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Original Article

Weight loss may be a better approach for managing musculoskeletal conditions than increasing muscle mass and strength

Bokun Kim[1)*], Takehiko Tsujimoto[2)], Rina So[2, 3)], Xiaoguang Zhao[1)], Shun Suzuki[4)], Taeho Kim[1)], Kiyoji Tanaka[2)]

1) Doctoral Program in Sports Medicine, Graduate School of Comprehensive Human Sciences, University of Tsukuba: 1-1-1 Tennodai, Tsukuba 305-8577, Japan
2) Faculty of Health and Sport Sciences, University of Tsukuba, Japan
3) Japan Society for the Promotion of Science, Japan
4) Master's Program in Health and Sport Sciences, Graduate School of Comprehensive Human Sciences, University of Tsukuba, Japan

Abstract. [Purpose] To prevent or remedy musculoskeletal conditions, the relationship between obesity and the characteristics of muscle mass and strength need to be clarified. [Subjects and Methods] A total of 259 Japanese males aged 30–64 years were classified into 4 groups according to the Japanese obesity criteria. Body composition was evaluated, and handgrip strength and knee extensor strength were measured for the upper and lower extremities, respectively. Physical performance was evaluated with a jump test. [Results] Obesity was positively correlated with skeletal muscle mass index, percentage of whole-body fat, and leg muscle strength and negatively correlated with the percentage of muscle mass index, body weight-normalized handgrip strength, and knee extensor strength, and the jump test results. [Conclusion] Weight loss may be a better approach than increasing muscle mass and strength to improve musculoskeletal conditions in obese adult males.
Key words: Obesity, Muscle mass, Muscle strength

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INTRODUCTION

Obesity is responsible for a wide range of chronic diseases, such as heart disease, hypertension and certain cancers[1, 2)]. Obesity is also associated with musculoskeletal conditions (MCs)[3–5)], such as pain, stiffness, loss of joint mobility and although these conditions are not fatal, they decrease quality of life and life expectancy by interfering with social exchanges and aggravating obesity.

The individual and social costs of MCs are considerable; The direct and indirect costs have reached $214.9 billion in the USA[3)], equivalent to three percent of the country's annual gross domestic product (GDP). In Europe, MCs have been recognized as having the highest cost burden of all disease categories[6)]. In Australia, the costs of MCs are second only to those of cardiac vascular diseases, the most cost-intensive disease category[7)]. Given these individual and socio-economic impacts, MCs require effective management.

*Corresponding author. Bokun Kim (E-mail: fabulousbobo79@gmail.com)

Muscle weakness and increased fat mass may be primary risk factors of MCs[8)]. Based on the premise that resistance training is desirable to increase muscle mass and strength, we have observed that muscle strengthening through resistance exercise increases physical function, decreases pain, and reduces self-reported disability[9–11)]. Exercises with weight bearing and a high joint loads, such as weight lifting and resistance training, may prove detrimental to obese individuals[12)]. Consequently, weight loss prior to exercise is recommended[13)]. Because previous studies have yielded inconsistent results, this study sought to investigate the relationship between obesity and muscle mass and strength to develop measures for MCs in obese male adults.

SUBJECTS AND METHODS

A total of 259 Japanese males aged 30–64 years were recruited via advertisement placed in local newspapers in Ibaraki from 2012–2015. The study inclusion criteria were as follows: 1) males aged 30–64 years; 2) no terminal diseases or history of recent muscle injury, or surgery; and 3) no history of drug or alcohol abuse. All participants provided informed written consent as approved by the institutional review board. This study was conducted in accordance with the guidelines proposed in the Declaration of Helsinki, and the study protocol was reviewed and approved by the ethics committee of the University of Tsukuba, Japan.

Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (YG-200; Yagami, Nagoya, Japan), and body weight was measured to the nearest 0.1 kg using a digital scale with the subject in light clothing and without shoes (TBF-551; Tanita, Tokyo, Japan). BMI was calculated as weight (kg) divided by height (m) squared.

Body composition was assessed using whole-body dual energy x-ray absorptiometry (DEXA; QDR 4500, Hologic, Inc., Bedford, MA, USA). The participants lay supine with their arms against the sides of their body. Hologic software was utilized to estimate the fat, lean, and bone tissue masses (kg). Extended analyses were performed to obtain separate fat, lean and bone tissue masses for the arms, legs, and trunk. Visser et al.[14] reported that lean mass, excluding bone mineral content, is a valid representation of skeletal muscle mass in the extremities. We calculated the appendicular skeletal muscle mass of each participant as the sum of the lean mass of both the upper and the lower extremities, excluding bone mineral content. A height-adjusted index was then calculated by dividing each participant's appendicular skeletal muscle mass in kg by the square of his or her height in m (m^2)[15]. The height-adjusted appendicular skeletal muscle index was defined as the skeletal muscle mass index (SMI). The percentage of muscle mass index (% MMI) was calculated by dividing each participant's appendicular skeletal muscle mass in kg by body weight, and multiplying the result by 100%.

To evaluate muscle strength, we measured handgrip strength for the upper extremities and knee extensor strength for the lower extremities. Handgrip strength has been widely adopted for the measurement of muscle strength because it is easy to measure. Knee extensor strength measurement is particularly important[16] because it evaluates the femoral muscle at the most common site of musculoskeletal conditions. Handgrip strength and knee extensor strength were measured and evaluated as described below. The participants gripped a dynamometer (Grip-D, T.K.K. 5401; Takei Scientific Instruments, Tokyo, Japan) in each hand alternately with maximum effort while lowering the arm naturally to the side of the body[17]. The measurement was performed twice for each hand, and the best result was recorded as the handgrip strength for each hand. Handgrip strength was expressed as absolute, body weight-normalized, and arm muscle mass (AMM)-normalized values. Isometric and isokinetic knee extensor strength were both measured using a Biodex System 3 dynamometer (Biodex Medical Systems, Shirley, NY, USA). The participants were seated in the Biodex System 3 dynamometer and tightly secured with chest, pelvis and thigh straps with the back supported and the hips flexed at 120°. The knee's axis of rotation and the Biodex System 3 dynamometer were precisely aligned before each test using visual inspection. The knee was extended to 60° for the isometric assessment because this angle provides the quadriceps with close-to-optimum muscle length for the production of maximal force[13]. The protocol of the isometric assessment consisted of 3 maximal extension efforts, each lasting 3 seconds with intervening 15-second rests. The isokinetic assessment comprised 3 maximal extensions at an angular velocity of 60°/s, as is widely used to evaluate isokinetic muscle strength[18]. The highest muscular force output at any moment during the assessment was defined as the peak torque and is reported in absolute terms (Nm) and normalized to body weight, represented as the body-weight-normalized (Nm/kg) peak torque. The amount of work accomplished for an entire assessment was defined as the total work and is reported as the absolute value (W), whereas the average of total work divided by time was defined as the average power, which is also reported as the absolute value (J). The measurements were performed on both legs, and the average strength of both legs was calculated to determine lower-extremity muscle strength[16]. The results are expressed as absolute, body weight-normalized, and leg muscle mass (LMM)-normalized values.

We used a jump test to discriminate between the physical performances of obese and non-obese individuals because it directly reflects the participants' lower extremity muscle strength and body weight. The test was performed as follows: the participants placed their feet on the circular board of the dynamometer (Jump-MD, T.K.K. 5106, Takei Scientific Instruments, Tokyo, Japan) with the dynamometer around their waist. The participants leaped vertically as high as possible using knee countermovement and landing on the circular board of the dynamometer. The assessment was performed twice, and the best result was recorded.

The measurement values are expressed as the means ± standard deviations (SDs) or standard errors (SEs). One-way analysis of variance (ANOVA) was used to analyze the differences between the groups. One-way analysis of covariance (ANCOVA), with age as a covariate, was utilized to test for the significance of mean body composition and muscle strength among the four groups. The Bonferroni post hoc test was used when the ANCOVA results exhibited significant differences ($p < 0.05$). The Jonckheere-Terpstra test was used to assess the trends among the values in the four groups. The trend test was 2-tailed, with a significance level of $p < 0.05$. SPSS software, version 18.0 (IBM, Inc., Armonk, NY, USA), was used for the statistical analyses.

RESULTS

The overall study sample consisted of 259 males aged 30–64 years. The participants were classified into groups A (non-obese, n = 60), B (obesity class I, n = 142), C (obesity class II, n = 47) and D (obesity class III, n = 10) based on Japanese obesity guidelines[19]. The anthropometric characteristics and trends among the 4 groups are presented in Table 1. The ANOVA results demonstrated that body weight and BMI differed significantly among the 4 groups. A progressive trend of decreasing age from group A to group D was observed (standardized statistic = −2.43, $p < 0.05$).

Table 2 presents the body composition results of the 4 groups. To avoid the influence of age on the results, ANCOVA was performed with age as a covariate. The post hoc tests demonstrated significant differences among the 4 groups for all of the variables. Groups A, B, C and D ranked in descending order for all variables except % MMI. The trend test also demonstrated increases from group A to group D for all variables except % MMI (standardized statistic = 10.40, 13.35, 9.78, 8.34, 7.16, 9.05, respectively; $p < 0.01$ for all). The % MMI trended in the opposite direction for all

Table 1. Anthropometric characteristics and trends among the four groups

	A. Non obesity (95% CI) (n = 60)		B. Obesity class I (95% CI) (n = 142)		C. Obesity class II (95% CI) (n = 47)		D. Obesity class III (95% CI) (n = 10)		post hoc	Standardized statistic[b]
Age, year	50.9±9.3	(48.5, 53.3)	50.3±9.0	(48.8, 51.8)	47.7±8.6	(45.2, 50.2)	44.0±8.5	(37.9, 50.1)	Ns	−2.43†
Height, cm	171.4±5.7	(169.9, 172.9)	171.5±6.1	(170.5, 172.5)	171.6±5.3	(170.1, 173.2)	172.8±6.4	(168.2, 177.3)	Ns	0.36
Body weight, kg*	69.0±6.1	(67.4, 70.6)	80.7±6.9	(79.6, 81.8)	94.1±7.7	(91.8, 96.4)	119.8±19.3	(106.0, 133.6)	A < B < C < D	13.95††
BMI, kg/m^2*	23.5±1.3	(23.1, 23.8)	27.4±1.4	(27.2, 27.7)	31.9±1.4	(31.5, 32.3)	40.0±4.9	(36.5, 43.5)	A < B < C < D	16.29††

Values are means ± SD. Significant group differences were found among the four groups (*p < 0.05). Significant trend was found among the four groups (†p < 0.05, ††p < 0.01). [b]Jonckheere-Terpstra test was used to assess the trend among the four groups. NS: not significant; BMI: body mass index

Table 2. Characteristics and trends of body composition among the four groups

	A. Non obesity (95% CI) (n = 60)		B. Obesity class I (95% CI) (n = 142)		C. Obesity class II (95% CI) (n = 47)		D. Obesity class III (95% CI) (n = 10)		post hoc	Standardized statistic[b]
Whole body lean mass, kg*	56.6±0.8	(55.1, 58.0)	61.7±0.5	(60.7, 62.6)	68.9±0.9	(67.2, 70.6)	76.8±1.9	(73.1, 80.4)	A < B < C < D[a]	10.40††
Whole body fat mass, kg*	13.3±0.5	(12.3, 14.3)	19.6±0.3	(18.9, 20.2)	24.5±0.6	(23.4, 25.7)	34.9±1.3	(32.4, 37.4)	A < B < C < D[a]	13.05††
% whole body fat, %*	18.9±0.5	(18.0, 19.9)	23.9±0.3	(23.3, 24.5)	26.0±0.5	(25.0, 27.1)	30.3±1.2	(28.0, 32.6)	A < B < C, D	9.78††
AMM, kg*	5.9±0.1	(5.7, 6.1)	6.4±0.1	(6.3, 6.6)	7.3±0.1	(7.0, 7.5)	7.7±0.3	(7.2, 8.2)	A < B < C, D[a]	8.34††
LMM, kg*	17.5±0.3	(16.8, 18.1)	18.7±0.2	(18.3, 19.2)	20.8±0.4	(20.0, 21.6)	23.1±0.9	(21.4, 24.8)	A < B < C, D[a]	7.16††
SMI, kg/m^2*	7.9±0.1	(7.7, 8.2)	8.5±0.1	(8.4, 8.7)	9.6±0.1	(9.3, 9.8)	10.5±0.3	(9.9, 11.1)	A < B < C < D[a]	9.05††
% MMI, %*	33.7±0.4	(32.9, 34.5)	31.1±0.3	(30.6, 31.7)	30.0±0.5	(29.1, 30.9)	26.4±1.0	(24.4, 28.4)	A > B, C > D	−7.03††

Values are means ± SE. Significant group differences were found among the four groups (*p < 0.05). Significant trend was found among the four groups (†p < 0.05, ††p < 0.01). [a]The Kruskal Wallis permutation test result was consistent with that of the ANCOVA analysis. [b]The Jonckheere-Terpstra test was used to assess the trend among the four groups. % whole body fat: percentage of whole body fat; AMM: Arm muscle mass; LMM: Leg muscle mass; SM: Skeletal muscle index; % MMI: percentage of muscle mass Index

the other variables (standardized statistic = −7.03; $p < 0.01$). These results indicate that both body fat and muscle mass increase in parallel with obesity.

Table 3 presents the muscle strength and physical performance results of the 4 groups. Multiple comparisons demonstrated significant differences among the 4 groups for all of the variables except LMM normalized strength. Although there was no trend in the absolute values of handgrip strength among groups A to D, the handgrip strength values normalized for body weight and AMM exhibited a statistically significant trend (standardized statistic = −8.82 and −6.66, respectively; $p < 0.01$ for both). The leg muscle strength absolute values did not differ significantly between groups A and B or between groups C and D but were significantly higher in groups C and D than in groups A and B. The trend test indicated that the absolute muscle strength value for each leg increased progressively from group A to group D (standardized statistic = 6.41, 6.30, 6.18, 5.32, respectively; $p < 0.01$ for all). When leg muscle strength was normalized for body weight, there were no significant differences among groups B, C and D aside from IKT60 AP/Body weight, although their values were significantly lower than those of group A. Although the IKT60 AP/Body weight values of groups A, B, C, and D were ranked in ascending order, no significant differences were observed between groups B and C or between groups C and D. IKT60 AP/Body weight was significantly higher in group A than in groups B, C and D. When analyzed for trend, the decrease in the body-weight-normalized leg muscle strength from group A to group D was statistically significant (standardized statistic = −3.08, −3.15, −3.23, −3.09, respectively; $p < 0.01$ for all). The jump test results decreased in value from group A through group D; the trend was significant (standardized statistic = −2.16; $p < 0.05$). The mean values of groups A, B and C did not differ significantly, although each was significantly higher than the value of group D. These results indicate that leg muscle strength correlates positively with increasing obesity, but the increases in leg muscle strength that accompany increases in obesity do not improve body weight-normalized leg muscle strength and physical performance.

DISCUSSION

Our primary finding is that body fat and muscle mass in-

Table 3. Characteristics and trends of muscle strength and physical performance among the four groups

	A. Non obesity (95% CI) (n = 60)		B. Obesity class I (95% CI) (n = 142)		C. Obesity class II (95% CI) (n = 47)		D. Obesity class III (95% CI) (n = 10)		post hoc	SS[b]
HGS, kg*	43.49±0.88	(41.77, 45.22)	42.14±0.57	(41.02, 43.26)	45.69±0.99	(43.73, 47.65)	44.18±2.16	(39.93, 48.43)	B < C	1.45
HGS/BW, kg*	0.63±0.01	(0.61, 0.65)	0.52±0.01	(0.51, 0.54)	0.49±0.01	(0.47, 0.51)	0.38±0.03	(0.33, 0.43)	A > B, C > D	−8.82††
HGS/AMM, kg*	7.42±0.12	(7.20, 7.65)	6.59±0.08	(6.44, 6.74)	6.31±1.13	(6.05, 6.57)	5.89±0.29	(5.33, 6.46)	A > B, C, D	−6.66††
IMT60 PTQ, Nm*	182.35±4.91	(172.68, 191.01)	194.78±3.19	(188.50, 201.06)	226.51±5.56	(215.56, 237.46)	235.67±12.09	(211.86, 259.49)	A, B < C, D	6.41††
IMT60 PTQ/ BW, Nm/kg*	2.63±0.06	(2.52, 2.75)	2.41±0.04	(2.34, 2.49)	2.42±0.07	(2.29, 2.54)	1.97±0.14	(1.70, 2.25)	A > B, C, D[a]	−3.08††
IMT60 PTQ/ LMM, Nm/kg	10.59±0.28	(10.03, 11.15)	10.51±0.19	(10.15, 10.87)	10.97±0.32	(10.34, 11.60)	10.43±0.70	(9.06, 11.81)	Ns	1.13
IKT60 PTQ, Nm*	156.23±4.08	(148.20, 164.26)	169.12±2.65	(163.91, 174.34)	192.30±4.62	(182.21, 201.40)	203.31±10.05	(183.52, 223.09)	A, B < C, D	6.30††
IKT60 PTQ/ BW, Nm/kg*	2.26±0.05	(2.16, 2.35)	2.10±0.03	(2.03, 2.16)	2.04±0.05	(1.94, 2.15)	1.72±0.12	(1.48, 1.95)	A > C, A > B > D	−3.15††
IKT60 PTQ/ LMM, Nm/kg	9.04±0.25	(8.56, 9.53)	9.13±0.16	(8.82, 9.45)	9.34±0.28	(8.80, 9.89)	9.00±0.60	(7.81, 10.19)	Ns	1.08
IKT60 TW, J*	440.22±11.77	(417.04, 463.39)	472.44±7.64	(457.39, 487.49)	535.28±13.33	(509.03, 561.53)	592.18±28.99	(535.08, 649.27)	A, B < C, D	6.18††
IKT60 TW/ BW, J/kg	6.36±0.14	(6.08, 6.64)	5.86±0.09	(5.68, 6.04)	5.70±0.16	(5.39, 6.01)	5.02±0.35	(4.34, 5.71)	A > B, C, D	−3.23††
IKT60 TW/ LMM, J/kg	25.47±0.66	(24.16, 26.77)	25.45±0.43	(24.60, 26.30)	26.06±0.75	(24.57, 27.54)	26.16±1.64	(22.94, 29.38)	Ns	1.02
IKT60 AP, W*	97.47±2.81	(91.94, 103.01)	103.53±1.82	(99.93, 107.78)	117.26±3.18	(110.99, 123.53)	130.57±6.92	(116.94, 144.20)	A, B < C, D	5.32††
IKT60 AP/ BW, W/kg*	1.41±0.03	(1.34, 1.48)	1.28±0.02	(1.24, 1.33)	1.25±0.04	(1.17, 1.32)	1.10±0.08	(0.94, 1.27)	A > B, C, D	−3.09††
IKT60 AP/ LMM, W/kg	5.65±0.16	(5.33, 5.97)	5.59±0.11	(5.38, 5.80)	5.69±0.19	(5.33, 6.05)	5.78±0.40	(4.99, 6.67)	Ns	0.75
Jump*	44.79±0.90	(43.01, 46.57)	42.84±0.59	(41.68, 43.99)	41.51±1.02	(39.50, 43.53)	32.20±2.23	(27.81, 36.59)	A , B, C > D	−2.33†

Values are means ± SE. Significant group differences were found among the four groups (*$p < 0.05$). Significant trend was found among the four groups (†$p < 0.05$, ††$p < 0.01$). [a]The Kruskal Wallis permutation test result was consistent with that of the ANCOVA analysis. [b]The Jonckheere-Terpstra test was used to assess the trend among the four groups. NS: not significant; HGS: Handgrip strength; BW: Body weight; AMM: Arm muscle mass; LMM: Leg muscle mass; IMT60 PTQ: Isometric60 peak torque; IKT60 PTQ: Isokinetic60 peak torque; IKT60 TW: Isokinetic60 total work; IKT60 AP: Isokinetic60 average power; SS: Standardized statistic

crease as obesity progresses. Leg muscle strength correlates positively with obesity; however, increases in leg muscle strength without weight loss do not improve body weight-normalized leg muscle strength and physical performance. Cross-sectional and interventional research has noted positive correlations between the loss of muscle mass and strength and MCs, and between the amelioration of MCs and muscle strengthening with resistance training[9–11]. However, the findings of the present study indicate that an increase in muscle strength requires an increase in muscle mass, which in turn increases body fat.

Body weight is a major determinant of muscle mass, and lean mass correlates positively with body fat[20, 21]. In the present study, we observed that SMI tended to increase as obesity increased, and that % whole-body fat increased as whole-body lean mass increased. These findings are consistent with the observation that heavier adult males have more muscle mass, and since muscle strength correlates positively with muscle mass, heavier adult males generate more muscle strength.

Maffiuletti et al.[22] reported that adult males with a BMI > 40 kg/m^2 had 18% more lean mass and created significantly more leg muscle power and maximum muscle strength (16–20%) than adult males with a BMI < 25 kg/m^2. This finding is consistent with the results of our study. A possible explanation for this finding is that the heavier body weights of obese adults serve as a training stimulus to gain muscle mass and, consequently, to increase muscle strength[23, 24]. Because the lower extremities' muscles must maintain and support all of the body's weight, these muscles are stimulated more strongly than those of the upper extremities. This condition likely accounts for the absence of significant obesity-related increases in handgrip strength despite the observed increases in every absolute value of leg muscle strength.

Body weight-normalized leg muscle strength is significantly lower in obese men than in non-obese men[22]. As the trend test indicated, the increase in whole-body fat mass (standardized statistic = 13.05) with increasing obesity was greater than the increase in whole-body lean mass (standardized statistic = 10.40). Excessive increases in body fat are a physical burden on the musculoskeletal system; as obesity develops, the amount of whole-body fat increases faster than whole-body lean mass does. Consequently, MCs may result from low body weight-normalized leg muscle strength[25]. Syed and Davis[26] reported that low body weight-normalized muscle strength results in earlier leg muscle fatigue and increases the loading rate on the knee joints. We also observed a significant decrease in the jump test results as obesity increased. These findings suggest that obese men must improve their body weight-normalized muscle strength to treat MCs. However, increasing muscle mass and strength without reducing body fat mass may not significantly improve body weight-normalized leg muscle strength. Therefore, losing body weight may be more appropriate than increasing muscle mass and strength for the treatment of MCs.

This was the first study in which Japanese obesity guidelines were used to study the relationship between obesity and muscle mass and strength in adult males. Although this cross-sectional study characterized the basis of the relationship between obesity and muscle mass and strength, scientific evidence of the benefits of body weight loss was limited. Consequently, two-pronged investigation comparing the effects of weight loss with that of resistance exercise in cohort and long-term follow-up surveys is necessary.

In conclusion, both body fat and muscle mass increase as obesity develops. Muscle mass and strength correlate positively with obesity. In the presence of obesity, increases in LMM and strength may not improve body weight-normalized muscle strength and physical performance. It may be easier to treat MCs with weight loss than with increased muscle mass and strength. To confirm the conclusion of the present study, a prospective cohort study and follow-up study should be conducted in the future.

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